The Opportunities and Limits for Socio-Environmental Sustainability in Fab Labs and Distributed Production

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Abstract

Researchers and writers studying new production-consumption practices have envisioned the potential to reduce the environmental impact of mass production through personal fabrication and 'distributed production', but these ideas remain largely concepts and visions. Fab Labs are well placed to explore these new ways of doing things: promoting better socio-environmental practices that synergize with new economic opportunities. However, ideology and vision do not dictate action plans, and critics are voicing concern that the maker movement is not delivering on its potential. Given the strength of the Fab Lab ideology, the Fab Academy and the network itself, Fab Labs are (arguably) the best actor in the maker movement to communicate its impacts; generate new knowledge, practices and solutions; and ensure making has meaning. Achieving this requires reflection and critical discussion: do our everyday actions reflect our vision, values and ideology? Environmental sustainability is but one thread in the socio-technical fabric of Fab Labs, but it is an integral thread. This essay reports on the discourse in Fab Labs and demonstrates, through examples from everyday events observed and heard in Labs, that environmental issues embed themselves within other issues in the Lab and ideology is not so easily enacted.

Keywords: environmental sustainability, distributed production, personal fabrication, ideology, environmental issues

Introduction

Increasing numbers of users have access to digital fabrication equipment via Fab Labs and makerspaces, which are mushrooming geographically. The technologies themselves, especially 3D printing, are widely espoused as disruptive technologies that will radically shift production and consumption patterns (Anderson, 2012; Marsh, 2012; Hamermesh, 2014).

Disruptive technologies combined with practices and values aligned with empowerment and peer learning means the Fab Lab model could well be a stepping stone to something new and different: more widespread implementations of distributed production, as an alternative to mass production. Many actors in the Fab Lab network and the 'maker movement' espouse personal fabrication as, in fact, a better alternative to mass consumption and consumerism. In Fab Labs the capacity to answer one's own needs is emphasized as a benefit, as opposed to being reliant on large corporate technology providers or 'satisficing' through passive consumption. Other espoused benefits are the enhanced skills people acquire to build, disassemble and repair, and the potential to distribute production within local networks as opposed to long, transport-intensive and large-volume supply chains. These propositions have clear environmental implications, from lessened environmental impact resulting from production only according to need, to more eco-efficient use of materials and products combatting planned obsolescence, to reduced negative impacts from transport emissions.

However little empirical research exists to confirm whether these benefits are coming to fruition or even on what actually happens in these forerunner makerspaces. The author's current research indicates that even when Fab Lab actors commit to a certain ideology and vision, they experience challenges in enacting it (Kohtala, 2013; Kohtala and Bosqué, 2014; Kohtala, in review). Moreover, even the most expert makers in Fab Labs do not necessarily have competence in sustainability assessment; likewise, the most ecologically oriented makers are not necessarily engaged with emerging technologies in this rapidly changing socio-technical environment (Kohtala and Hyysalo, 2015). There are also unknown impacts of digital fabrication that remain unaddressed and have potential to cascade, should it become more mainstream (Drizo and Pegna, 2006; Huang et al., 2013; Olson, 2013; De Decker, 2014; Short et al., 2015). To a network of actors committed to the betterment of their communities of users, these conditions present challenges.

This paper brings together key findings in several long-term studies in the author's doctoral research that employed several methods (primarily ethnographic). The essay will summarize the current understanding of environmental issues in distributed production; summarize the discourses that espouse the sustainability benefits of distributed peer production; discuss the gap between discourse and practice as observed in several Fab Labs; and propose opportunities for environmentally responsible practices in Fab Labs as found in the author's ethnographic research. The objective is to prompt discussion on positive future directions among the audience of this paper: the actors in Fab Labs themselves.

Research on Distributed Production
'Distributed production' as a term does not have a commonly endorsed definition, but it is often used as a synonym for 'distributed manufacturing' and connotes a re-configuration of user/consumer-producer relationships, the roles of intermediaries in the supply chain and production and consumption activities (i.e. 'prosumption' [Toffler, 1980; Xie et al., 2008; Ritzer and Jurgenson, 2010]). It carries potential to stretch to the ideological or visions of new 'paradigms' when speaking of alternatives and "opportunities for more socially beneficial and responsive production and consumption" (Kohtala, 2014, 2). This is the case, for instance, when actors analyse – or seek to stimulate – production modes and regional development as "distributed economies": when "a selective share of production is distributed to regions where a diverse range of activities are organised in the form of small-scale, flexible units that are synergistically connected with each other and prioritise quality in their production", "departing from the socio-economically and environmentally unsustainable dynamics associated with large-scale, centralised production units" (Johansson et al., 2005, 971).

Research on the environmental hazards and opportunities in distributing production is only now emerging, given the dominance of mass production. In a review of 29 studies from diverse fields, which included research on sustainable mass customization as well as fabbing and making (see Figure 1), surprisingly few studies involved empirical data. Many articles remained conceptual and explorative, which indicates that, first, the phenomenon is new and evolving and, second, researchers appear uncertain how to even study the environmental benefits of distributing production in this way.
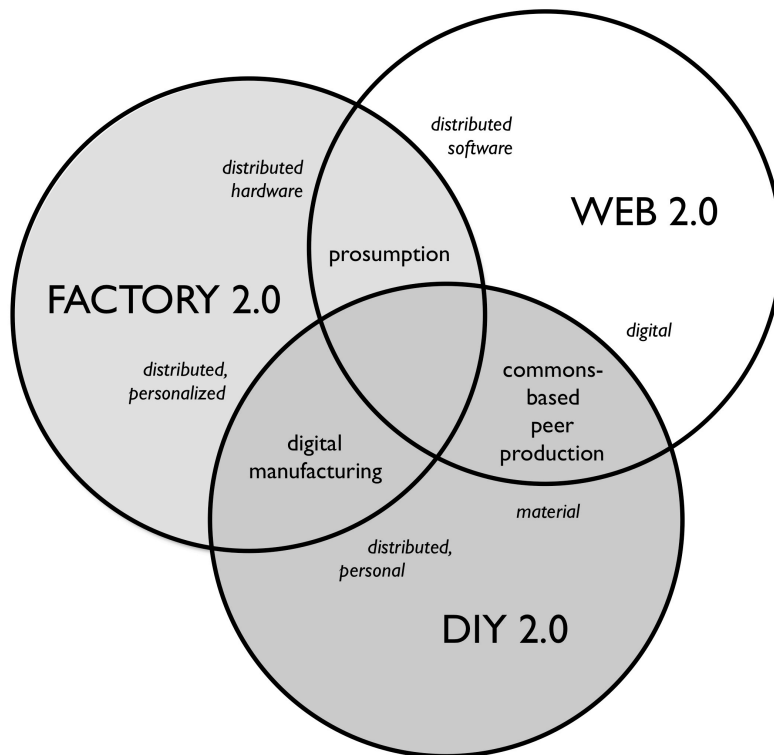
Figure 1: The scope of research on distributed material production (in gray). Source: Kohtala, 2014, 3.

Part of the challenge lies in dealing with complexity and large system boundaries if one is comparing mass production to distributed production. Figure 2 illustrates the environmental issues in these new production modes, where most of the empirical research now being conducted tends to fall in the gray-shaded topical areas. (This research includes energy consumption studies on additive manufacturing processes, for instance. See Kohtala, 2014.) One can well argue for the need to better understand the issues, opportunities and threats, on the neglected right side of Figure 2, if only to confirm that e.g. Fab Labs are indeed moving in the right direction, but how would a researcher or research group embark on such a study? Hielscher and Smith (2014, 44) point out the limits to methods such as LCA (life cycle assessment) studies and argue that, "[g]enerating insights into the contending narratives influential in digital fabrication developments ... might be a more fruitful line of inquiry. Studying the cultures of production and consumption cultivated in workshops and other sites of take up seem to be key, and therefore how technologies are valued and used". Before discussing these contending narratives, how Fab Lab culture is enacted and how sustainability issues interweave among these narratives and practices, the following section will describe how the research community sees the future environmental sustainability of distributed production.
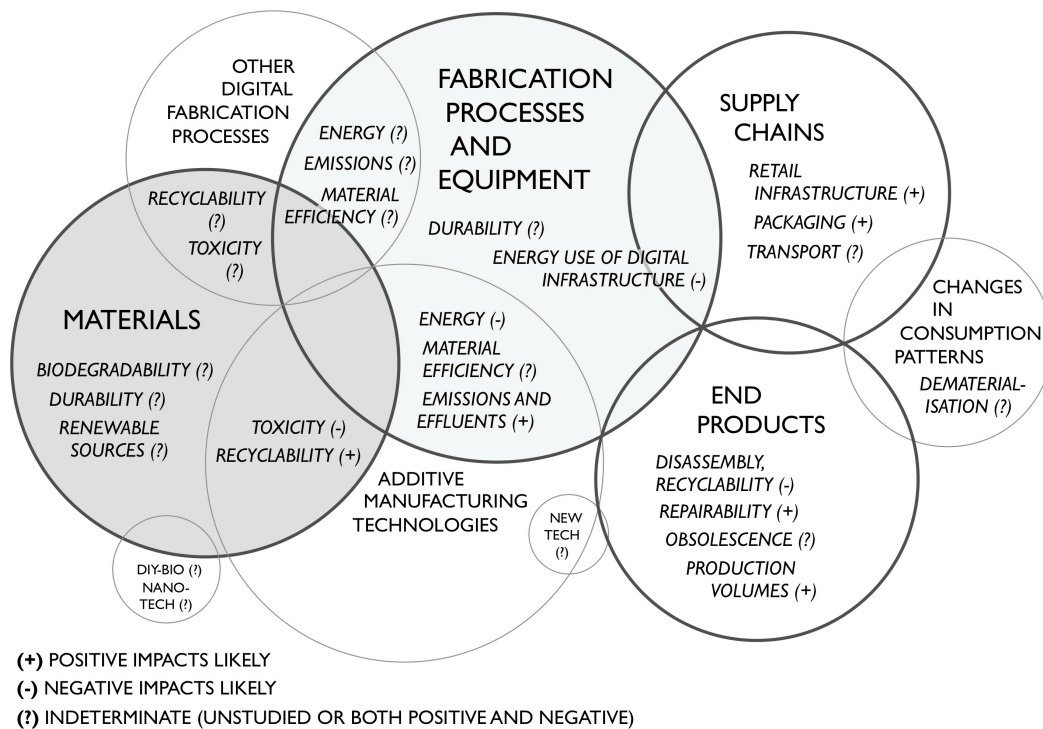
Figure 2: Overview of the environmental issues in distributed production and personal fabrication. Source: Kohtala and Hyysalo, 2015, 335.

The Environmental Sustainability of Distributed Production
Based on the analysis of the literature (Kohtala, 2014), conceptualizations of distributed production can be summarized as depicted in Figure 3. Most research in the literature review examined activities in the bottom left corner, mass customization, with fewer studies examining personal fabrication (top left) (the small number-letter combinations represent the papers in the literature review). The remaining two quadrants were given working titles and could be regarded as possible future activity areas that may emerge and grow in future.
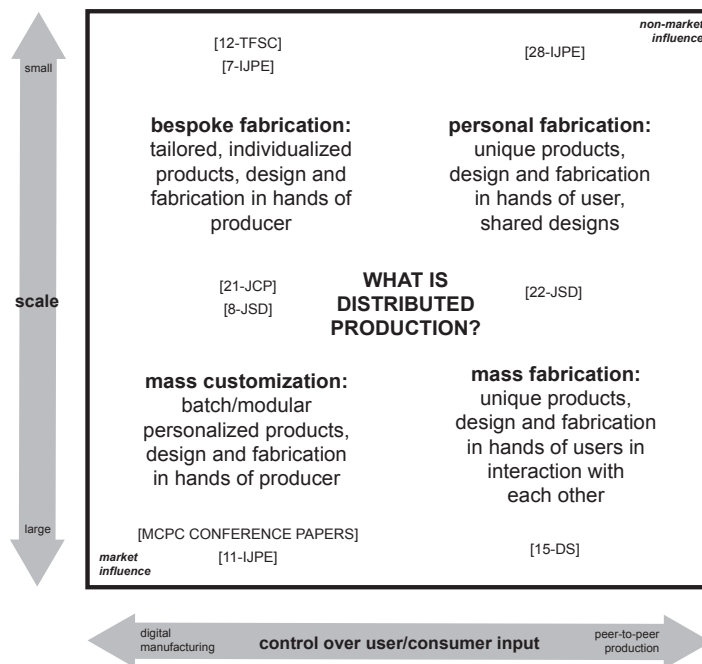
Figure 3: How distributed production can be conceptualized. Source: Kohtala, 2014, 8.

The authors of the reviewed studies proposed environmental benefits to distributed production as depicted in Figure 4, but, as stated, many of these studies were conceptual and not based on empirical testing, model testing or case studies in real life practice (or this testing/data gathering was not explicated in the paper). An oft-repeated proposition was that users who fabricate their own products (or are involved in its design or production in some significant way) will keep and use the product longer, forming a distinct attachment and experiencing a high level of product satisfaction that can combat our current 'throwaway society' conditions. Another often-seen theme was the reduction of negative environmental impacts connected to transport emissions, as production would be done locally.
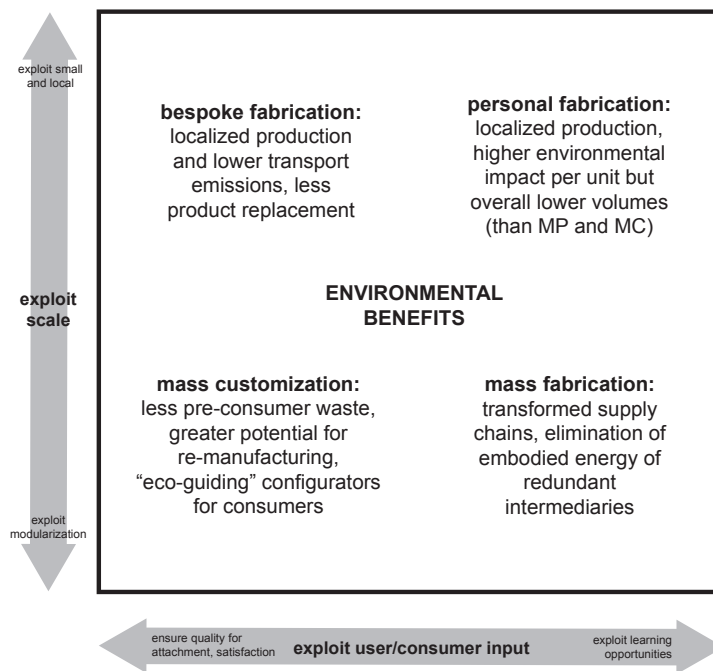
Figure 4: How authors in the research literature see environmental sustainability opportunities in distributed production. Source: Kohtala, 2014, 8.

This raises a number of obvious questions. How localized is personal fabrication, really? Are local sources of materials or equipment prioritized or is only the production process itself distributed and local? Are Fab Lab users truly learning how to build, assemble, repair, reassemble products, possibly keeping them and using them for a longer period, and/or answering their own needs, according to Fab Labs' own ideology and the propositions presented here? Moreover the literature was less forthcoming on the potential environmental problems a distributed production paradigm can carry with it, and these issues remain blind spots in our understanding (Figure 5). The fact that several digital fabrication processes have unknown impacts on both human health and the environment is attracting attention (Huang et al., 2013; Stephens et al., 2013; Short et al., 2015), and Fab Labs may need to consider more robustly how the issues scale to the level of personal fabrication.
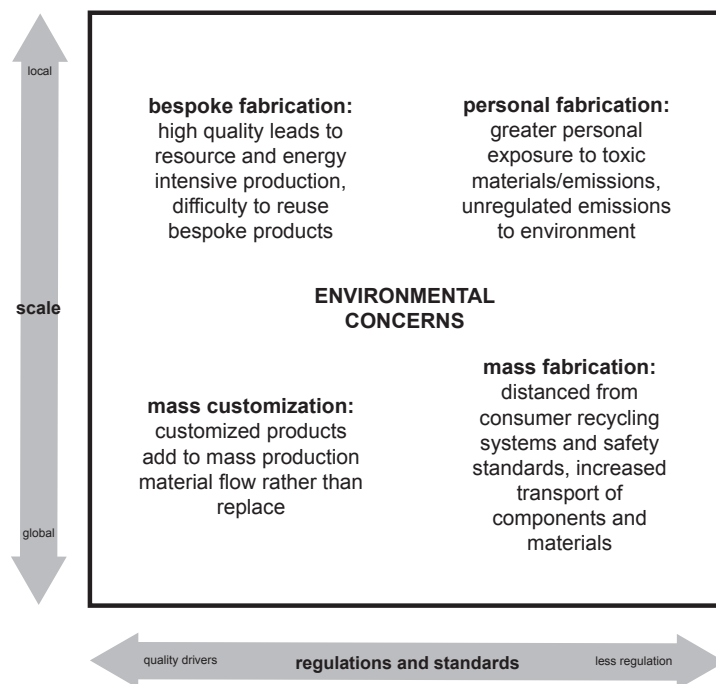
Figure 5: Potential environmental issues in distributed production that were not (or little) covered in the examined research literature. Source: Kohtala, 2014, 12.

On the positive side, Fab Labs provide benefits by being shared, open, peer-learning spaces, removing health, safety and emission problems away from the home or office and boosting the potential for eco-efficient use of shared equipment (Faludi et al., 2015). Given the increasing critical attention paid to energy-hungry digital fabrication tools, Fab Labs could promote the energy-efficient aspect of shared use, but also pay closer attention to daily electricity consumption (encouraging better troubleshooting and problem prevention, combining jobs, powering down, explicitly choosing green energy sources, etc.).

Fab Labs and makerspaces may also prove to be the ideal testing ground for solutions that are best distributed and localized rather than under centralized control. Low-tech energy technologies are the most obvious example (Hielscher and Smith, 2014, 44), while others could be explored and – in so doing – better documented for the benefit of both practitioner-makers and policymakers. The Michigan Tech Open Sustainability Technology research group is remarkably prolific with studies on solar energy (King et al., 2014) and plastic recycling (Krieger et al., 2013; Hunt et al., 2015), and numerous other topics, in distributed manufacturing and fabrication. (Critics have questioned the quality and robustness of some of this group's studies, but the group's researchers consistently address topics implicating open source hardware, open design that is environmental sustainability oriented, appropriate technology development and peer-to-peer, distributed activities in a way many other university-based research groups do not.) Additionally, several actors (often practitioner-researchers) in personal fabrication are active in developing recycle bots for plastics (RecycleBots, FilaBots, etc.).

Finally, the immense pool of valued, specific knowledge and competence in Fab Labs on fabrication processes, electronics, components, materials and what they can do has not gone unnoticed, as NGOs and civil activists probe the lessons fabbing and making provide on the potential to shift to more environmentally-led remanufacturing and circular

economy patterns and practices. The Ellen MacArthur Foundation events, the Future Makespaces for Redistributed Manufacturing project and Open Source Circular Economy Days are examples that have seen enthusiastic Fab Lab participation and contribution. This work is in progress and research findings and publications forthcoming.

The Common Understanding and Visions of the Future
Interestingly, but unsurprisingly, the same propositions on the environmental benefits of distributed production described above are also promoted by more mainstream writers who describe making and fabbing as the next revolution. Chris Anderson, for instance, wrote: "...as 3-D printers proliferate and are used for small-scale bespoke or custom-made manufacturing, they can provide a more sustainable way of making things. There are little or no transportation costs, because the product is made locally. There is little or no waste, because you use no more raw material than you need. And because the product is custom-made just for you, you're more likely to value it and keep it longer. Personalized products are less disposable; you simply care about them more" (Anderson, 2012, 86). Jeremy Rifkin even claimed that, "The 3D printing movement is deeply committed to sustainable production. Emphasis is on durability and recyclability and using nonpolluting materials" (Rifkin, 2014).

Why these visions pertain to Fab Labs is particularly because these books sit on the bookshelves in Fab Labs (as photographed by the author during fieldwork) and many of these authors are invited to speak at the annual FABx Symposiums; they therefore form part of the Fab Lab network's own mythology building. According to Rifkin (2014), "[t]he Fab Lab is 'the people's R&D laboratory' of the Third Industrial Revolution. It takes R&D and new innovations out of the elite laboratories of world-class universities and global companies and distributes it to neighborhoods and communities where it becomes a collaborative pursuit and a powerful expression of peer-to-peer lateral power at work." This is a familiar description of the Fab Lab network, but also an expression of a utopian future vision, where "a local 3D printer can power [an] infofactory with green electricity harvested from renewable energy onsite or generated by local producer cooperatives." In this future, "[t]he software instructions for printing objects are globally shared rather than privately held, yet the material feedstocks are locally available, making the technology universally applicable." Moreover this future looks very different from the one we are living in today: "Fab Labs are the new high-tech arsenals where DIY hackers are arming themselves with the tools to eclipse the existing economic order." (It should be duly noted and remembered throughout the discussion in this essay that the *existing economic order* is commonly espoused as undesired.) The environmental benefits of this new paradigm are obvious, from local material stocks to renewable energy, and they interweave and synergize with the socio-economic benefits.

Even an anarchist writer like Kevin Carson (2010) promotes Fab Labs as one route to an "alternative economy" by citing a 2009 discussion in the Open Manufacturing Google group on the Indian examples Gershenfeld (2005) describes in FAB: where overheads, capital outlay and waste are low and there is "superior efficiency in using limited resources intensively" (Carson, 2010, 314; see 314-316 for a summary and extracts from the forum thread and/or Cravens, 2009). Indeed, the Fab Labs in the global South appear to be delivering what Fab Labs promise. But what of Labs in the North, in post-industrial economies and wealthy contexts, who do not in principle have the limited resource inputs from the outset? Are they too ensuring democratic access to the means of production, for the welfare of neighbourhoods and communities? Do they express any interest in using "limited resources intensively" or pay attention to their material inputs and outputs?

Ideology goes only so far – we must examine if and how it is being enacted in practice. A discussant in the Google group asked accordingly: "There is no (valid) sophistry here, no prose or politics, just the undeniable truth of whether or not those fablabs *work*, whether they are doing their job, or doing what they look they are doing..." (Bishop, 2009, emphasis in original). The original poster countered that as long as "fabs are and remain open source, easy and affordable to replicable [sic]", they may contribute to the post-scarcity transition being discussed (Cravens, 2009).[1]

These utopian future visions (some of them clearly techno-utopian) feature people and actions in the future, but what of the present? Visions and ideology may guide action plans, but we must not underestimate the constraints actors in Fab Labs experience in their everyday, mundane routines and the conventional societal structures they exist within, as well as against. As Maxigas and Troxler write (2014), "if these narratives are the only things created by these new places, it might not be enough to really change anything in the way people can or allow themselves to reconfigure their socio-material practices."

The Lie of the Land
To be provocative, there seems to be a widespread understanding in the Fab Lab network that 'we are not *un*sustainable'; this assumption, however, does not make Fab Labs and their continued evolution benign and healthy by default, automatically contributing to a better society. By the same token, this paper may seem to focus on tangible material and energy flows in a context that is marginal and therefore carrying a relatively low environmental burden. Indeed, fostering (socio-)environmental sustainability in this new 'revolution' goes beyond simply reusing components and materials (or using 'bio-materials') in the Fab Lab, and the author is loathe to reduce the environmental discussion to "the naive and emphatic economics of sustainable development" (Maxigas and Troxler, 2014).

That said, the materials and technologies in Labs, and how the actors in a Fab Lab social world (Strauss, 1978) shape their meanings as well as material forms, reveal much about how these materials stand for – in fact *mediate* – access, participation and other important values in Labs. As Marres (2012) points out, participating in these new 'democratizing' peer-to-peer activities is negotiated by material means (see also Ratto and Boler, 2014). The stuff in a Fab Lab is the channel (or material, or material *assemblies*; Shove et al., 2007; 2012) by which people become inspired and involved, participate, contribute, learn, interact with external stakeholders, seek monetary profit, initiate DIWO projects, become disengaged, communicate vision, include some in interaction, while blocking others. It thus embodies ideology and intent as much as convenience and convention. In this understanding, printer filament waste does not only represent wasted natural resources (and Lab finances); it becomes intractably entangled in issues around user time and frustration (thus feelings of satisfaction and accomplishment versus lack of 'empowerment'); technology design decisions (thus feelings of estrangement from the very tools of 'liberation'); recycling (thus symbolizing dependent or independent relationships with existing infrastructure and institutions); materiality (from the aesthetics of plastics to concern about Peak Oil); and so on. Regarding the material aspect in Fab Labs, shortcuts taken and actions that become the default in both routines and problem situations have consequences and may reveal much about a Fab Lab's possible future trajectory.

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[1] The economic discussion in Carson (2010) and the Google group, while central, has been radically simplified or not summarized here for reasons of space and scope.
[2] i.e. visits to thirteen Fab Labs in Europe, mainly grassroots Labs, including observations and interviews;

In fact, given the fanfare around revolution, there appears to be little attention paid thus far (by both researchers and Fab Lab actors) to *routines* and routinization (Strauss, 1993), rendering Fab Labs as black boxes even to insiders. In the author's fieldwork and interviews,[2] one salient condition is remarkably consistent and will resonate among the audience of this paper: Fab Lab managers are extremely busy and they need to wear many hats. This means they need to consciously schedule in time for discussion on strategy, reflection on vision, work on action plans, not to mention activities to maintain their own skills and learning. Many know they benefit from the Fab Lab network and communicate via the polycom, regularly turning to their colleagues globally for advice and support, while others are less well connected and may not have attended Fab Academy. They know that they would benefit from attending the regional Fab meetings but struggle to find the time. Some managers have been able to build up a roster of reliable volunteers and/or interns to help them assist users, while others struggle and still others are restricted from using volunteers (e.g. for insurance reasons in a highly regulated environment such as a university). Many managers want to strengthen connections to geographically neighbouring communities, but they find it challenging and their efforts inconsistently successful. The most persistent (and well-known) challenge is 'documentation': Fab Labs want users to document and share their work (and users want to too), but this is not happening to the extent desired (Wolf et al., 2014). All this is widely known in the community, but perhaps still further real-life examples are needed to hammer home the point that espoused beliefs and values do not immediately translate into action on the ground.

To borrow Troxler's (2014) classification of grassroots and hosted Labs, Labs that are hosted by institutions (such as universities) are especially subject to others' routine arrangements and structures. In the author's ethnographic research in one particular Fab Lab (Kohtala, in review), procurement procedures are largely *not* dictated by strategies to foster local, neighbourhood collaboration (or even local economies) nor prioritize locally available feedstocks, but rather by convenience: suppliers already in the host university's supplier list and/or MIT's inventory. In the same case study, an open source CNC mill had been built collaboratively in the Lab by a group of enthusiastic delegates in an international open hardware festival event, but subsequently the mill remained unused. A year or more later, a large ShopBot was purchased, but it is so difficult to use that the Fab Lab managers must monitor and direct its use, thus compromising the open access and self-directedness so valued they are embodied in the Fab Charter. On the other hand a Fab Lab in the southern hemisphere reported in an interview that (to paraphrase) sustainability has dictated their procurement regime which has subsequently become routine to both Lab organizers and users. As the locally produced MDF is toxic, users are not allowed to use it; nor does the Lab import the more 'eco' MDF from Europe because of the transport emissions and impacts. Moreover, this university-hosted Lab channels its non-toxic sawdust to be combined with the bio-waste from the university's catering services in worm composting, and the compost is used in the university's gardens. These are clear socio-material practices deliberately configured to conform to a particular (environmentally-oriented) vision. The Valldaura Self-Sufficiency Lab provides many more similar examples, a consistently presented identity and vision enacted in practice visibly and explicitly. It is thereby praised in Fab Lab mythology (Lassiter, 2013) as well as greatly admired by visitors such as the FAB10 delegates.

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[2] i.e. visits to thirteen Fab Labs in Europe, mainly grassroots Labs, including observations and interviews; interviews with managers, directors and users from five other Labs in Europe and the Asia-Pacific region (India, Japan, Taiwan and New Zealand); and a three-year-plus ongoing longitudinal ethnography in a northern European Lab

In contrast, grassroots Labs have fewer institutional constraints and can establish their own procedures in their own ways, even while the actors come from their own backgrounds and conventions. The problem grassroots Labs face in securing financing can easily override everything else, including espoused commitments, values or manifestos. (This is clearly the case in hosted Labs too.) Routines may become established based on a particular individual's repetitive activities (which become repetitive in the interest of time-saving and efficiency) (Strauss, 1993). This is problem free except when the routine comes into conflict with espoused values. One Lab manager, for instance, expressed concern to the author about his colleagues, who were content to have users simply reproduce existing designs in order to learn the tools and processes; he would instead have preferred to spend the extra time encouraging users to learn to *design* for digital fabrication as well as learn to print. A similar concern was conveyed in an opinion piece by Pinto (2015): "A review of the websites of several Ontario makerspaces reveals that participating children are merely producing objects in tandem using various technologies, but following very prescriptive instructions such that the output by each student was identical. ... The Torontoist reported on [a local library-based] lab last winter, describing how elementary students watched a 3D printer layer filament to make a chess piece. Other children used 3D printers to create a fine-tooth comb and key fobs with the library's logo. There is no making or even learning here. The students do not appear to be engaged in creativity or innovation; they are mere spectators of the production of crafts using state-of-the-art technology."

This should cause concern to Fab Labs, given the high importance placed on the Labs' role in education (Blikstein, 2013, and many others). New Labs (and labs new to education) may need to be reminded that activities and interactions (and their consequences) should be considered consciously, regularly reflected upon, and critiqued. An instructive example in a German Lab is given by Posch (2013, 66): "Among the most important achievements of digital fabrication technologies is its implementation of objects of personal need that are not covered or beyond the reach of the mass market. Therefore, we want to preserve this important aspect, giving children the possibility to make something of personal use they might not get elsewhere. Within the scope of the workshop modules, they work on individual projects rather than repeating predefined tasks." Routines (such as assigning users learning tasks or ordering equipment) are helpful and structuring – when they do not go unexamined and question the Lab's core reason for being. They thereby communicate both internally and externally what the Lab prioritizes. The objective in these paragraphs is not to scold or praise these individuals, makerspaces and their decision-making, but rather to highlight and make explicit the daily choices we *all* make and how contingencies (situated interactions and conditions at that particular time and place; Strauss, 1993, 36-37) conspire and congeal into compromises we might otherwise not have made. Over time these compromises accumulate, but we may not be conscious of how.

Another example is seen in the desire to promote micro-entrepreneurship. A headline in a recent Wall Street Journal article announced, '3-D Printer Users Opt for Trinkets: Fab Labs Looking to Foster the Next Entrepreneurs Find Many Users Just Want to Make Doodads'. The article went on: "... many of the people drawn to these shops are using them to make art or trinkets, rather than launching businesses. ...'Entrepreneurship has been hard and elusive,' said MIT's Ms. Lassiter. Leaders of an association of U.S.-based Fab Labs at a recent meeting established a task force to spur more entrepreneurial activity..." (Hagerty, 2014). There are no easy answers here, but discussing solutions is – as seen here – likely best accomplished in the distributed regional networks rather than as a solution-for-all. The issue nevertheless illustrates that goals and visions do not simply manifest.

The Critics and the Critical

This leads back to the question of what Fab Labs are for. Critics of the maker movement argue that the virtuous goal of promoting local socio-economic opportunities for maker inventors and micro-entrepreneurs is being overshadowed by the promise of success of another kind: measured in economic profit and ensuring this profit by proprietary, protectionist means (as large corporations tend to do), precisely the elements Fab Labs were set up to counter (Morozov, 2014; Draitser, 2015; Fonseca, 2015). Sadowski and Manson (2014), for instance, wrote: "There's real collective democratic freedom to be gained from the maker movement. But it needs to shake off simplistic economic individualism and hypercapitalistic politics if makers want to represent a disruption of the existing economy. ...What the maker movement needs is to embrace more social views of the technologies' potential — views oriented toward helping people do more than just play with tools and make personalized schlock." The vision of a maker society Anderson presented is seen as producing merely "exclusive knick-knacks for the anomic plutocracy" (Poole, 2012).

The critics are becoming increasingly noisy. The criticism is directed especially at 3D printing, but this does not and will not shelter Fab Labs from the critical fallout. Smith (2012) coined the memorable term 'crapjects' to describe precisely the doodads, trinkets and knick-knacks mentioned above, which may overtake more useful and beneficial projects done in makerspaces: "We can't count on the positive potential of an innovation to completely eliminate all possibility of negative externalities," he wrote. Similarly, in a blog post that went viral, Arieff (2014) argued that "the absence of sustainable discourse" in the maker movement was worrying and wanted to ensure DIY and making developed as "an alternative to consumerism rather than a direct line to it."

Not all the critics are outsiders. The call for critical discussion is also coming from inside the Fab Lab network via e.g. the LinkedIn interest group and publications (Nascimento, 2014; Maxigas and Troxler, 2014; Troxler, 2014), and this is healthy. But what *is* the state of things on the ground? In hackerspaces and similar communities, Moilanen and Vadén (2013) and Ratto and Ree (2012) actually report on a variety of projects undertaken – not simply doodads and ultimately 'crapjects'. Grimme et al. (2014, 438) report on the hacker scene and a study in a hackerspace: "For many, the act of making itself is critical, political, or anti-consumerist.... For others, this is a problematic conceptualization of making, whether because of the consumption ecologies created by new making tools such as 3D printers and Arduino, or the simple fact that we have yet to see making have an integral impact on a broad scale.... In our own interviews these assertions are problematized. While some of our makers specifically cite a desire to critique or subvert a specific infrastructure, system, or ideology, in many cases making activities happened because they were cheaper, faster, or just plain fun."

During the author's fieldwork, a manager in a European Fab Lab expressed concern, unprompted, that many Fab Labs seemed to be focusing only on "toys". He wanted to build up his Lab and its vision towards meaningful things serving the regional community. He had visited Valldaura in 2014 and had been greatly inspired: there, "it's not about laser cutting baby cars, it's about using the laser cutter to produce things that matter, that have function, that have a reason to be built." In another European Lab located in a university, the manager organized courses that emphasized completing a whole, cohesive design project (including the potential business model), to enhance students' ability to design for digital fabrication, to lead them to a better understanding of the relationship between the

bit and the atom in personal fabrication, and to avoid mere reproduction of useless objects. In the courses the students engaged in long discussions on the issues surrounding making and Fab Labs, including the relationship between digital fabrication and traditional high craftsmanship, the potential to be co-opted by large corporations and the options for revenue and design projects in open design processes.

From both inside and outside, making is often seen (i.e. dismissed) as fun, playful and hobbyist, especially in wealthy post-industrial contexts. Here again the issue of materiality rises to the fore and how socio-environmental sustainability interweaves itself among these issues: too much attention and time devoted to the developing and printing of toys and trinkets is waste, a waste of time, human creativity, energy and natural resources. The meaning of making is too easily lost and its potential for local community empowerment unfulfilled. Of course, Fab Labs cannot be draconian: managers cannot and should not forbid making as fun and play and prevent users from designing or printing toys and trinkets. Nevertheless desired activities, stakeholder connections and the necessary related skills and competences could be identified, as well as locally appropriate ways of fostering them. For inspiration we may turn to the HCI community, who is increasingly discussing the battle of ideology and the ethics, socio-environmental sustainability and meaning of making in their conferences and critically-minded activities in their own spaces (Ratto, 2011; Ratto and Boler, 2014; Toombs et al., 2015; Sun et al., 2015; and many others).

How Fab Labs communicate what they are for and how they frame their relationship to the existing economy appears inconsistent at best, dangerously apolitical and non-critical to outsiders. In an early survey, for instance, this description of Fab Labs places them squarely in the existing mass production economy they are meant to overthrow: "Fab labs come into play before an object moves into the chain of production. They enable rapid prototyping but are not suited to production on a larger scale (a limited number of identical pieces can be made if the hardware is not overused), nor are they suited to distribution, repair, or recycling" (Eychenne, 2012, 7). This immediately arrests alternative identities that some *do* associate with Fab Labs: creative reinvention, the reuse of material and the competence to disassemble, reassemble and fix – alongside the invention of entirely new, local solutions to local problems.

Conclusions: Beyond Ad hoc Ashrams
From a practical, pragmatic perspective, taking on the tangible environmental issues raised in this paper in explicit, visible and communicable ways would differentiate the Fab Lab network as the most clearly responsible and responsive player in the maker movement. This may even become central to survival for hosted Labs who must demonstrate ethical and responsible practice to stakeholders and sponsors. If this work is indeed underway (and the author suspects there are many more stories to be told), it is not reaching e.g. the mass media. Older Labs have also expressed concerns about younger Labs and if they 'get' the point of Fab Labs, not being simply seduced by 'cool' technologies. Older Labs themselves know how their own values may succumb to the undertow of lack of time, funding stress and mundane daily routines.

For those Labs wanting to commit to explicitly ecological-led solutions in the spirit of sustainable development, discussion could begin on how to form an effective distributed 'Special Interest Group' where ideas for solutions, tools and workshops could be shared. Manuals and guidelines could be initiated by this group for internal Lab use, including information on material and process toxicity (promoting the examination and posting of

MSDS sheets in Labs, for instance), best practices in reuse and recycling, and energy conservation.

New relationships could also be explored. Among the Labs the author has examined, two Labs are actually reaching out to neighbourhood organizations, private companies or NGOs, to share larger and more expensive equipment, enacting a novel part of a distributed economy vision where production is indeed geographically distributed but still within 'local' networks. This also ensures efficient use of the fabrication equipment.[3]

Sustainability is itself a going concern and a moving target, necessitating a continuous, generative dialogue and reflection on what it means to Fab Labs in all its dimensions – especially given the rapid development of technologies and materials. To benefit from the high expertise and competence in the Fab Lab network, this understanding is best constructed in ongoing dialogue between the most expert (in technological terms) makers and eco-committed makers (Kohtala and Hyysalo, 2015). The challenge to bring these groups together, to engage a diverse range of participants will remain, as well the lack of time, but regional events such as FabFuse offer potential for such meetings of minds.

In terms of Fab Labs' role in the community and society, there could be more stories and narratives on how Fab Labs are contributing to a sustainable distributed economy paradigm: engaging in research and with researchers to fill in the gaps in the diagrams and issues discussed in the first sections of this paper, and articulating how environmental concerns intertwine with the existing concerns of education and entrepreneurship. From this standpoint, the author's intent with this paper accords with Benkler and Nissenbaum (2006): "Unlike many political analyses of technologies, however, ours does not warn of a direct threat of harm. Rather, it warns of a threat of omission. We might miss the chance to benefit from a distinctive socio-technical system that promotes not only cultural and intellectual production but constitutes a venue for human character development."

The author recognizes several limits to her own research as well as Fab Lab history. On the one hand, the author has only been involved with Fab Labs since 2011 and the research has focused on European Labs (especially northern Europe). Even so, from the ethnographic perspective, Fab Labs everywhere do share common problems and time and resource constraints so stories will resonate and some findings are generalizable. The trajectories of the older Labs in the network are especially instructive (Kohtala and Bosqué, 2014).

On the other hand, the Fab Lab network is young and still evolving. We are not far past the situation described in another Open Manufacturing group discussion in 2009, where Eric Hunting wondered why take-up of open manufacturing and the maker movement was proceeding so slowly: "People are learning by making, but they never seem to get the whole picture of what they potentially could make because they aren't getting the complete picture of what the tools are and what they're capable of.... Remember the early days of the personal computer? You had these fairs, users groups, and computer stores like Computer Shack basically acting like ad hoc ashrams of the new technology because there were no other definitive sources of knowledge. This is exactly what Maker fairs, Fab Labs, and forums like this one are doing" (as cited in Carson, 2010, 249).

Communities in Fab Labs are living the future today. As the network develops and matures, dissemination of information will become more cohesive, less ad hoc and capable

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[3] This type of municipality-wide facility and equipment sharing was also discussed among maker participants in Kohtala and Hyysalo (2015). See also Hyysalo et al. (2014).

of greater impact. With conscious reflection, strategic action and effective communication, Fab Labs can support resilient communities capable of surviving today's economic uncertainties and environmental constraints.

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